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BOEING 747 AIRCRAFT WITH EXTERNAL CARGO POD

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EXTERNAL CARGO POD (Vought Corp., Hampton,  
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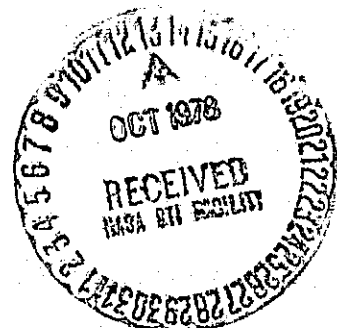
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## SUMMARY

An analysis was conducted to investigate the feasibility of mounting a detachable pod to the underside of the fuselage of a Boeing Model 747 aircraft to carry outsized cargo in case of military emergency.

The analysis showed that the 747 configured with the pod and carrying only a bridge launcher as payload attained a range of 8.70 Mm (4 700 n. mi.) at Mach .68. This range was based on a maximum take-off gross weight of 3.447 MN (775 000 lbf) which included 212 kN (47 700 lbf) pod weight and 543 kN (122 000 lbf) payload (bridge launcher). To achieve the above range, the 747 carrier airplane was stripped of non-essential items including its landing gear, which becomes unusable because of the height of the pod. A fixed-gear or completely retractable pod-mounted gear will replace the original 747 gear. No pressurization was provided in the pod and, therefore, a military restriction to 5.5 km (18 000 ft) cruise altitude for unpressurized cargo applies.

## INTRODUCTION

The objective of this study was to determine the feasibility of mounting a removable, external pod on the Boeing 747 aircraft for carrying military cargo. Criteria for the feasibility of the concept were, to minimize the modifications to the carrier aircraft, and the installation time required to attach the external pod to the Boeing 747.

A mobile bridge launcher was specified as the largest single piece of equipment that the pod would need to accommodate. This bridge launcher has a weight of 543 kN (122 000 lbf) and requires a minimum cargo compartment height of 4.11 m (13.5 ft), a width of 4.27 m (14.0 ft), and a length of 9.30 m (30.5 ft). These dimensions included clearances between the launcher and the cargo compartment structure.

Another criterion was the capability of the 747 with pod and bridge

launcher payload to cover at least the distance from the east coast of the United States to Europe without refueling at the military restricted altitude for unpressurized cargo of 5.5 km (18 000 ft).

Because of the height of the pod, the 747 existing landing gear was replaced by a gear on the pod. A pod was configured and evaluated in conjunction with three different types of pod-mounted landing gear. This evaluation included the pod weight and a structure analysis; the structural mating of the pod with the carrier; the aerodynamic drag and the range performance penalties imposed by the pod; and the method of mating the pod to the 747.

### SYMBOLS

$C_D$	drag coefficient $D/q_s$	ORIGINAL PAGE IS OF POOR QUALITY
$C_L$	lift coefficient $L/q_s$	
$D$	drag	
$L$	lift	
$M$	Mach number	
$T$	absolute temperature	
$T_0$	absolute temperature at sea level standard day	
TSFC	thrust specific fuel consumption	
$a_0$	speed of sound at sea level/standard day	
$\theta$	temperature ratio, $T/T_0$	

### RESULTS AND DISCUSSION

#### Configuration

A configuration design study was made for mounting a detachable pod against the bottom of the Boeing 747 aircraft for hauling outsized cargo,

specifically a mobile bridge launcher or an M60 tank. The internal cargo volume of the detachable pod was configured to accommodate the mobile bridge launcher envelope since it was the largest of the two pieces of military equipment specified. A clearance of .46 m (18 in) was provided between the pod side structure and the payload envelope for accessibility to the tie down fittings and for other flight or ground crew activity within the cargo area. The bridge launcher payload center of gravity was at the 747 mid-travel center of gravity.

Clamshell doors (similar to the aft doors on the C-141) and a loading ramp that retracts inside the cargo area, were provided at the rear of the pod with sufficient clearances to permit straight-in loading (figs. 1 and 2).

Because of the height of the pod, the existing 747 main landing gear and the nose gear cannot be used. This landing gear system can either be left on the aircraft in the retracted position, to save conversion time, or removed to save weight. The replacement landing gear consists of a four-strut main gear and a single-strut nose landing gear mounted to the pod. All taxi, take-off, and landing loads would be borne by this gear system.

The forward portion of the pod was extended forward to the Boeing 747 fuselage station 400 bulkhead and shaped to provide for mounting the replacement nose gear to the pod. This resulted in moving the nose gear position from station 390 to station 770 in order to keep the strut to an acceptable length. The relocation necessitated changing the nose gear from a two-wheel truck to a four-wheel truck because of the increased tire loads. The aircraft tip-over angle was still within the acceptable design specifications limit.

Three preliminary design concepts of the pod-mounted landing gear were made for weight and drag evaluation: a retractable gear system that is fully enclosed within landing gear blisters (fig. 1); a fixed-gear system

enclosed within landing gear blisters and wheel covers (fig. 2) except for tire protrusion sufficient to prevent damage to wheel fairing structure with two flat tires; and a fixed fully-exposed wheel and strut design (fig. 3). The latter gear arrangement was abandoned because of the unacceptably large aerodynamic drag.

Five primary structural attachments of the pod to the 747 aircraft were selected: at fuselage station 400 (nose-landing-gear bulkhead); station 1000 (center-wing-box front spar); station 1241 (center-wing-box rear spar); station 1350 (forward landing-gear-beam bulkhead); and station 1480 (aft-landing-gear bulkhead). The nose landing gear vertical loads would be reacted by shear in the 747 fuselage station 400 bulkhead and in the center-wing-box front spar at fuselage station 1000. For this purpose a truss type construction was incorporated at the forward end of the pod in the shape of a triangle with the base corner points fastened to the station 400 bulkhead and to the front spar, respectively. The forward main, pod mounted, landing gear vertical loads would be reacted by shear in the center-wing-box rear spar at fuselage station 1241 and the landing-gear-beam bulkhead at fuselage station 1350. The aft main landing gear vertical loads are absorbed by shear in the fuselage bulkhead at station 1480. Transfer of these loads from the landing gear to the 747 structure would be through heavy bulkheads in the pod. Transfer of horizontal drag loads between pod and 747 fuselage would be by means of shear and would occur mainly in the region of the main-landing-gear attachments.

To achieve a snug mating of the pod to the 747 carrier, secondary attachment points will be necessary at certain intervals along the length of the pod. These points were not defined in this study.

### Structural Analysis

A preliminary strength analysis was conducted on the configurations shown in figures 1 and 2. The results of this analysis were utilized to size structural members for the configuration design and weight evaluation.

Criteria adapted for the strength and weight analysis included: utilization of the existing 747 wing and fuselage hardpoints; minimum impact on the basic 747 airframe; simple, reliable and fast pod attachment; and an unpressurized pod. The limit load factors were 2.5 g down (positive maneuver), 2.0 g up (taxi), 1.0 g side (maneuver), and 6.0 g forward (crash). A safety factor of 1.5 was used.

Aluminum was selected as the material for the pod. Forgings of 2014-T6 aluminum alloy are used for the landing gear support frames and their attachments to the 747 fuselage. The pod skin, formed frames, and built-up floor beams are made of 7075-T6 aluminum alloy. The wheel fairings and all doors are also 7075-T6 aluminum alloy limited to .064 cm (.025 in) as a minimum gauge. The landing gear utilizes primarily high heat-treated steels; namely, 4340 alloy with a strength of 1.930 GPa (280 ksi). In tension applications, the strength allowables were reduced to provide satisfactory fatigue life. Otherwise MIL-HDBK-5B room temperature "A" values were utilized.

The critical loading condition for most of the pod structure and attachments was the 2.0 g limit (3.0 ultimate) taxi condition. The main gear was also critical in this condition; the critical load being 2.531 MN (569 000 lbf) (ultimate) per strut. The nose gear taxi load of 1.067 MN (240 000 lbf) (ultimate) was much larger for the pod than the 547 kN (123 000 lbf) (ultimate) load for the basic aircraft. This was caused by the shorter distance between the nose and main gear for the pod configuration than for the basic aircraft.

The landing gear frames at fuselage stations 1342.5 and 1463.5 (fig. 1 and 2) were analyzed as rigid frames for carrying the gear loads to the 747 attachments. The nose gear frame was analyzed as a simple truss. The pod skin and formed frames carry the gear drag and crash loads, along with relatively small airloads. The pod drag loads were sheared into the 747 structure primarily in the region of the main gear attachments. Concentrated loads induced by the payload determine the floor beam sizes.

The weight associated with the above structural sizing of the pod and

landing gear configurations was presented in the weight analysis discussion.

### Weight Analysis

A weight analysis was conducted for the two pod configurations shown in figures 1 and 2. One pod was configured with a retractable pod-mounted gear housed in blisters on the pod (fig. 1); the other pod incorporated a fixed pod mounted gear, which is partially enclosed by blisters on the pod and fairings or covers on the wheels (fig. 2). The pod and pod-mounted landing gear weights were determined by using the prediction methods of reference 2 and a mass properties computer program developed by the Vought Corporation Hampton Technical Center. The results are shown in table I. The partially enclosed fixed gear version (fig. 2) incorporated a cantilever landing gear arrangement. This results in heavier gear support frames (due to the load path) than the retractable gear configurations (fig. 1); however, this weight increase was more than offset by the simpler and, therefore, lighter gear.

A preliminary analysis was conducted to determine the potential weight saving that would accrue from replacing, wherever possible, aluminum and steel with composites. This preliminary analysis indicated that the pod structure and gear assembly weight could be reduced approximately 15 percent from 199 kN (44 700 lbf) to 168 kN (37 800 lbf). A more detailed analysis may show additional weight savings from the use of composites.

The 747-200B aircraft was selected as the carrier in this study based on availability of weight data for this model. It was assumed that the furnishings (seats) and the majority of the standard and operational items (galley, food, etc.) would be removed prior to or during the pod attachment operation. It was further assumed that the 747 landing gear would be removed (if adequate time was available) to save weight, since it becomes unusable.

Weight breakdowns of the basic 747 and of the aircraft with the pods are presented on table II. If the original landing gear had to remain on the airplane, the empty weight values for the configurations with pod would be 144 kN (32 300 lbf) higher than shown.



In this study, the maximum takeoff gross weight was limited to 3.447 MN (775 000 lbf). Since the pod equipped with the fixed gear was somewhat lighter than the pod with the retractable gear, the loaded aircraft with the fixed gear can be fueled to capacity while the take-off gross weight remains slightly below the maximum current value.

### Aerodynamic Drag

The minimum parasite drag of the 747 with pod was determined using a computer program developed by the Vought Corporation Hampton Technical Center. For the input to this program, the pod was treated as a lower-lobe enlargement of the 747 fuselage.

Changes in compressibility drag were ignored since the airplane with pod was estimated to fly in a low speed regime where compressibility effects will be negligible.

The minimum parasite drag of the combination of the 747 and the pod was increased by the drag created by the pod-mounted landing gear. Three different types of landing gear were investigated. The simplest of these consisted of fixed fully-exposed wheels and struts as shown in figure 3. Since this arrangement resulted in a total airplane drag which exceeded the available thrust, it was eliminated from further consideration.

A more complex gear arrangement (fig. 2) was considered in which the fixed gear was nearly completely encased in blisters on the pod. As in the case of the cargo pod discussed above, the pod mounted landing gear blisters and wheel covers were treated as part of the fuselage in the computation of the parasite drag; however, an additional blister-drag contribution (to account for flow separation and derived from unpublished Lockheed C-5A data) was included. The drag caused by the exposed parts of the wheels was estimated from reference 3. The resulting drag polar for the aircraft with pod, blisters, wheel covers, and partially exposed wheels is shown in figure 4.

The third landing gear evaluated for possible use on the study airplane

was of completely retractable type housed in pod mounted blisters (fig. 1). This gear does not contribute to the airplane drag during climb and cruise; however, the blisters will impose a penalty which was determined in the same manner as for the partially exposed fixed arrangement. The main gear blisters for this gear concept were smaller in size than those for the fixed type, since, in that case, the blister width was determined by the gear track. The retractable gear does not require a nose wheel blister.

Figure 4 presents the drag polars for the airplane with the pod and the two landing gear arrangements and also, as a reference, the estimated polar for the basic aircraft. The minimum parasite drag increases incurred by installing the pod were found to be approximately 0.0061 (37%) with the partially exposed fixed gear, and 0.0037 (23%) with the retractable gear.

Lift-drag ratios, corresponding to the polars of figure 4, are presented in figure 5. Compared to the lift-drag ratio for the basic 747 at  $M \leq .72$ , the reductions in maximum L/D because of the pod, amount to approximately 17 percent with the partially exposed fixed gear, and 11 percent with the retractable gear.

### Mission Analysis

The range capability was evaluated with the externally mounted cargo pod loaded with a 543 kN (122 000 lbf) bridge launcher. The pod was not pressurized; therefore, the cruise altitude had to be limited to 5.5 km (18 000 ft) since a military specification specifies this as the maximum altitude for transportation of equipment in a non-pressurized environment.

As the first step in the mission analysis, the airplane drag and available thrust at the 5.5 km (18 000 ft) altitude were determined as functions of velocity. The drag was based on the polars of figure 4, and the thrust was based on available P&W JT9D-7 engine data. The results, (fig. 6) show that the drag of either concept was less than the available cruise thrust.

Subsequently, Breguet range factors were calculated as a function of

velocity for both configurations. These range factors (fig. 7) indicated that the cruise Mach numbers for maximum range were .66 and .68, for the two pod configurations. It was assumed that no significant compressibility drag would occur at these Mach numbers since the basic aircraft compressibility effects were negligible for Mach numbers less than .72.

A payload-range plot was generated with data from various sources for the Boeing 747-200B aircraft at long range cruise speed ( $M = .84$ ). A range factor of 25.61 Mm (13 830 n. mi.) was calculated for the basic aircraft at  $M = .84$  and an estimated initial cruise altitude of 9.1 km (30 000 ft). The ratios of the maximum range factors for each of the two podded configurations to that of the basic 747 were then determined. These ratios were .72 for the pod with the fixed, partially exposed, landing gear and .79 for the pod with the retractable gear. Then, the ranges for which the basic airplane required the same amount of total mission fuel as that available on the podded versions were found. These ranges were then multiplied by the Breguet-factor ratios to obtain the ranges of the aircraft with the pods. Ranges were determined carrying a 543 kN (122 000 lbf) mobile bridge launcher and with the original landing gear either left in the aircraft (to save conversion time) or removed (to save weight). It was assumed that the maximum take-off gross weight and fuel capacity for the configurations with the pod remained the same as for the basic aircraft, and that the aircraft with the pods operated with commercial airline fuel reserve requirements. The calculated ranges are presented in table III together with the corresponding values for the basic aircraft.

#### Mating of Pod Onto Carrier Aircraft

Methods to attach the pod to the Boeing 747 were reviewed briefly. One procedure which appeared feasible employs a pit in the ground with a ramp. After the pod has been positioned in the pit, the 747 would be moved on top of it, supported by the outboard gear on the edges of the pit. The width of the pod exceeds the track of the outboard 747 landing gear and the pit must be shaped with overhanging edges as shown in figure 8. It would be necessary to remove or retract the inboard 747 landing gear beforehand, and to temporarily

install a removable gang-plank type of support over the pit for the 747 nose gear until the mating is completed and the airplane rests on the pod mounted gear. After attachment, the pod with the 747 on top would be towed out of the pit. The overhanging edges would have to end before the beginning of the up-ramp.

## CONCLUSIONS

A study was conducted to determine the feasibility of mounting a detachable pod to the underside of a Boeing model 747 aircraft to provide a means of carrying outsized cargo in case of a military emergency. The principal results of this study were as follows:

1. Five main attachment points of the pod to the 747 were selected located at the 747 nose gear bulkhead; the front and rear spars of the center wing box; the forward main landing gear bulkhead; and the aft main landing gear bulkhead.
2. Because of the height of the pod, the original 747 landing gear would have to be replaced by a gear mounted on the pod. The pod mounted gear either should be retractable or nearly completely enclosed. A simple fully exposed wheel and strut arrangement was found to increase the total airplane/pod drag above the available cruise thrust level.
3. The original 747 landing gear could be removed to exchange its weight of 144 kN (32 300 lbf) for additional fuel if the time required for removal was not prohibitively long.
4. The empty weight of the pod was estimated at 199 kN (44 600 lbf) with an attached nearly completely enclosed fixed landing gear, and 212 kN (47 700 lbf) with a retractable gear.
5. The addition of the pod was estimated to increase the basic 747 minimum parasite drag by 23 percent for the version with the retractable pod

mounted gear, and by 37 percent with the partially exposed fixed gear. The maximum lift to drag ratios for the aircraft with the pod and the above two landing gear configurations were 11 percent and 17 percent, respectively, below the basic 747 value at low speed.

6. The range values achievable with a mobile bridge launcher weighing 543 kN (122 000 lbf) as payload and at a Mach number of approximately .67 were from 7.04 Mm (3 800 n. mi.) to 8.70 Mm (4 700 n. mi.) depending on the type of pod mounted landing gear and on whether the original 747 landing gear is removed or left in the airplane.
7. This cursory study did not reveal any aspects which would render the above concept infeasible.

## REFERENCES

1. Department of Defense: Military Standardization Handbook, Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5B, 1 September 1971.
2. Oman, B. H.: Vehicle Design Evaluation Program. NASA CR-145070, January 1977.
3. Biermann, David and Herrnstein, William H.: The Drag of Airplane Wheels, Wheel Fairings, and Landing Gears, II - Nonretractable and Partly Retractable Landing Gears. NACA Report 518, 1935.

TABLE I. - POD STRUCTURAL WEIGHT BREAKDOWN

Item	Pod Config. with Fixed Partially Exposed Gear		Pod Config. with Retractable Gear	
	kN	lbf	kN	lbf
Landing Gear Support Frames				
Station 770 (Nose Gear)	4.0	900	4.0	900
Station 1342.5	18.3	4 100	9.3	2 100
Station 1463.5	8.9	2 000	8.9	2 000
Floor Beams	8.0	1 800	8.0	1 800
Pod Skins and Frames	17.3	3 900	17.3	3 900
Landing Gear Fairings	5.3	1 200	3.6	800
TOTAL POD	61.8	13 900	51.1	11 500
Main Gear (Pod Mounted)	114.8	25 800	135.7	30 500
Nose Gear (Pod Mounted)	22.2	5 000	25.4	5 700
TOTAL GEAR	137.0	30 800	161.1	36 200
TOTAL POD AND GEAR	198.8	44 700	212.2	47 700

TABLE II. - WEIGHT BREAKDOWN OF AIRCRAFT WITH EXTERNAL POD

	Basic 747-200B (1)		Aircraft Plus Pod with Fixed Partially Exposed Gear		Aircraft Plus Pod with Retractable Gear	
	kN	lbf	kN	lbf	kN	lbf
STRUCTURE	845.6	190 100	845.6	190 100	845.6	190 100
LANDING GEAR	143.7	32 300	0	0	0	0
PROPULSION	205.5	46 200	205.5	46 200	205.5	46 200
SYSTEMS	111.7	25 100	111.7	25 100	111.7	25 100
FURNISHINGS	181.0	40 700	0	0	0	0
PAINT	3.1	700	3.1	700	3.1	700
MANU. EMPTY WEIGHT	1490.6	335 100	1165.9	262 100	1165.9	262 100
STD. & OPERATIONAL ITEMS	151.2	34 000	11.1	2 500	11.1	2 500
OPERATING WEIGHT EMPTY (O.W.E., - AIRCRAFT ONLY)	1641.8	369 100	1177.0	264 600	1177.0	264 600
PASSENGERS	351.1	78 925	0	0	0	0
CARGO	348.9	78 475	0	0	0	0
POD + GEAR	0	0	198.8	44 700	212.2	47 700
O.W.E. OF A/C + POD	0	0	1375.8	309 300	1389.2	312 300
POD PAYLOAD	0	0	542.7	122 000	542.7	122 000
ZERO FUEL WEIGHT	2342.0	526 500	1918.5	431 300	1931.9	434 300
FUEL	1118.7	251 500	1520.0	341 700 (2)	1515.5	340 700 (3)
TAKE-OFF GROSS WEIGHT	3447.4	775 000	3438.5	773 000	3447.4	775 000
MAX. LANDING	2508.7	564 000	2508.7	564 000	2508.7	564 000
MAX. RAMP WEIGHT	3460.7	778 000	3460.7	778 000	3460.7	778 000

1. Boeing weight statement
2. 193 056 liter (51 000 gal) @ 7.87 N/liter (6.7 lbf/gal) (max. capacity)
3. 190 569 liter (50 343 gal) @ 7.87 N/liter (6.7 lbf/gal)



TABLE III. - MISSION RANGE AND CRUISE SPEED

	A/C with Pod Range Mm n.mi.	Boeing 747 Range Mm n.mi.	Mach Number	
			A/C with Pod	Basic 747
° 747 with pod and pod mounted retractable landing gear				
°° original L.G. removed	8.70 4 700	11.11 6 000	.68	.84
°° original L.G. left in.	7.41 4 000	9.45 5 100	.68	.84
° 747 with pod and pod mounted partially exposed fixed landing gear				
°° original L.G. removed	7.96 4 300	11.11 6 000	.66	.84
°° original L.G. left in	7.04 3 800	9.63 5 200	.66	.84

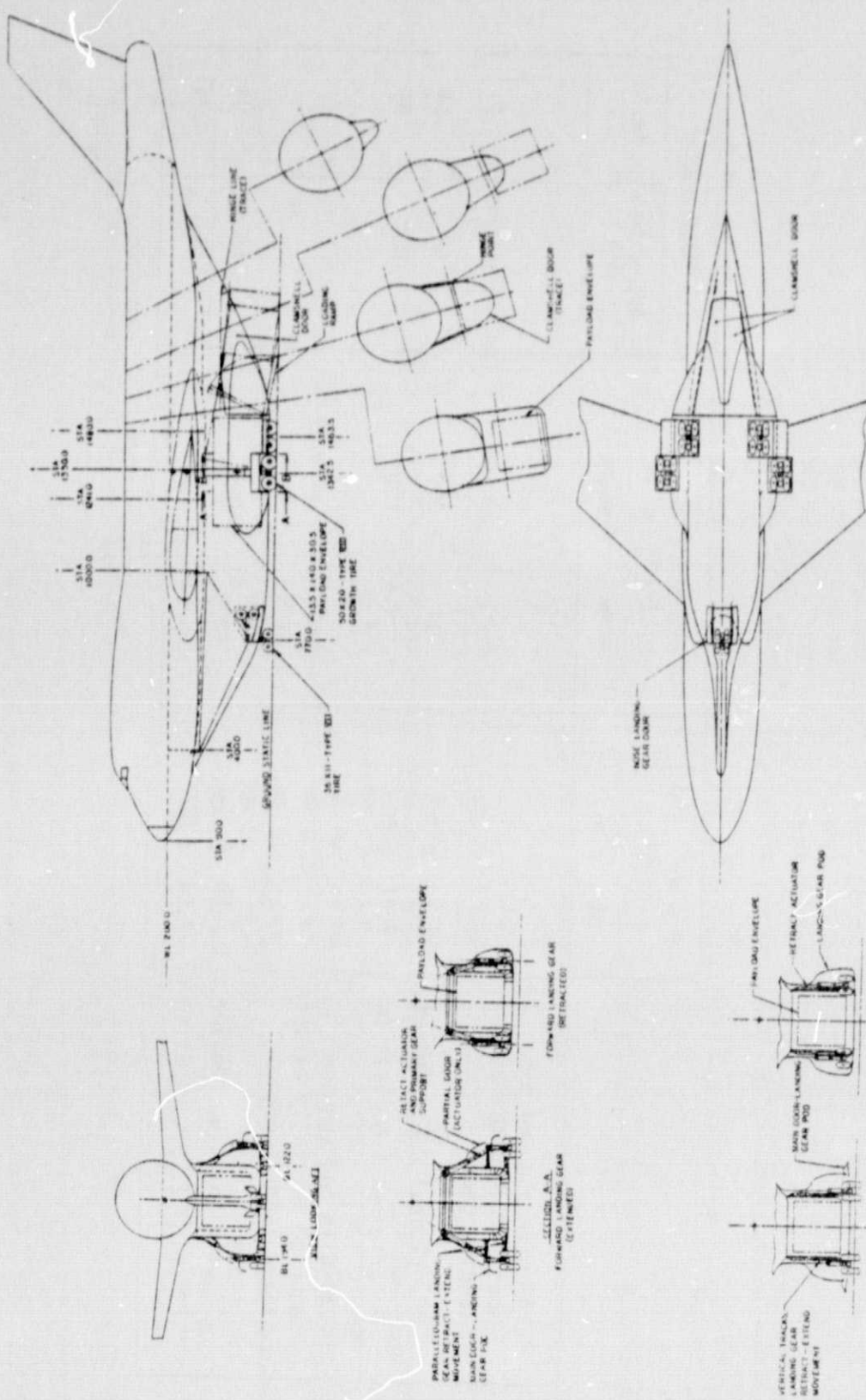


Figure 1. - Boeing 747 with external cargo pod - retractable landing gear.

This technical drawing illustrates the landing gear and cargo loading capabilities of a military transport aircraft. It includes the following components:

- Top View (Left):** Shows the aircraft's profile with stationing (STA 1000.0 to STA 1480.0) and the location of the clamshell door and loading ramp.
- Front View (Bottom Left):** Details the main landing gear assembly, including the oleo strut, fixed non-retractable landing gear, and the fixed forward landing gear.
- Side View (Right):** Shows the aircraft's profile with the clamshell door and loading ramp.
- Front View (Bottom Right):** Details the main landing gear assembly, including the oleo strut, fixed non-retractable landing gear, and the fixed forward landing gear.
- Side View (Left):** Shows the aircraft's profile with the clamshell door and loading ramp.
- Front View (Bottom Left):** Details the main landing gear assembly, including the oleo strut, fixed non-retractable landing gear, and the fixed forward landing gear.
- Side View (Right):** Shows the aircraft's profile with the clamshell door and loading ramp.
- Front View (Bottom Right):** Details the main landing gear assembly, including the oleo strut, fixed non-retractable landing gear, and the fixed forward landing gear.
- Side View (Left):** Shows the aircraft's profile with the clamshell door and loading ramp.
- Front View (Bottom Left):** Details the main landing gear assembly, including the oleo strut, fixed non-retractable landing gear, and the fixed forward landing gear.
- Side View (Right):** Shows the aircraft's profile with the clamshell door and loading ramp.
- Front View (Bottom Right):** Details the main landing gear assembly, including the oleo strut, fixed non-retractable landing gear, and the fixed forward landing gear.

Figure 2. - Boeing 747 with external cargo pod - fixed, partially exposed, landing gear

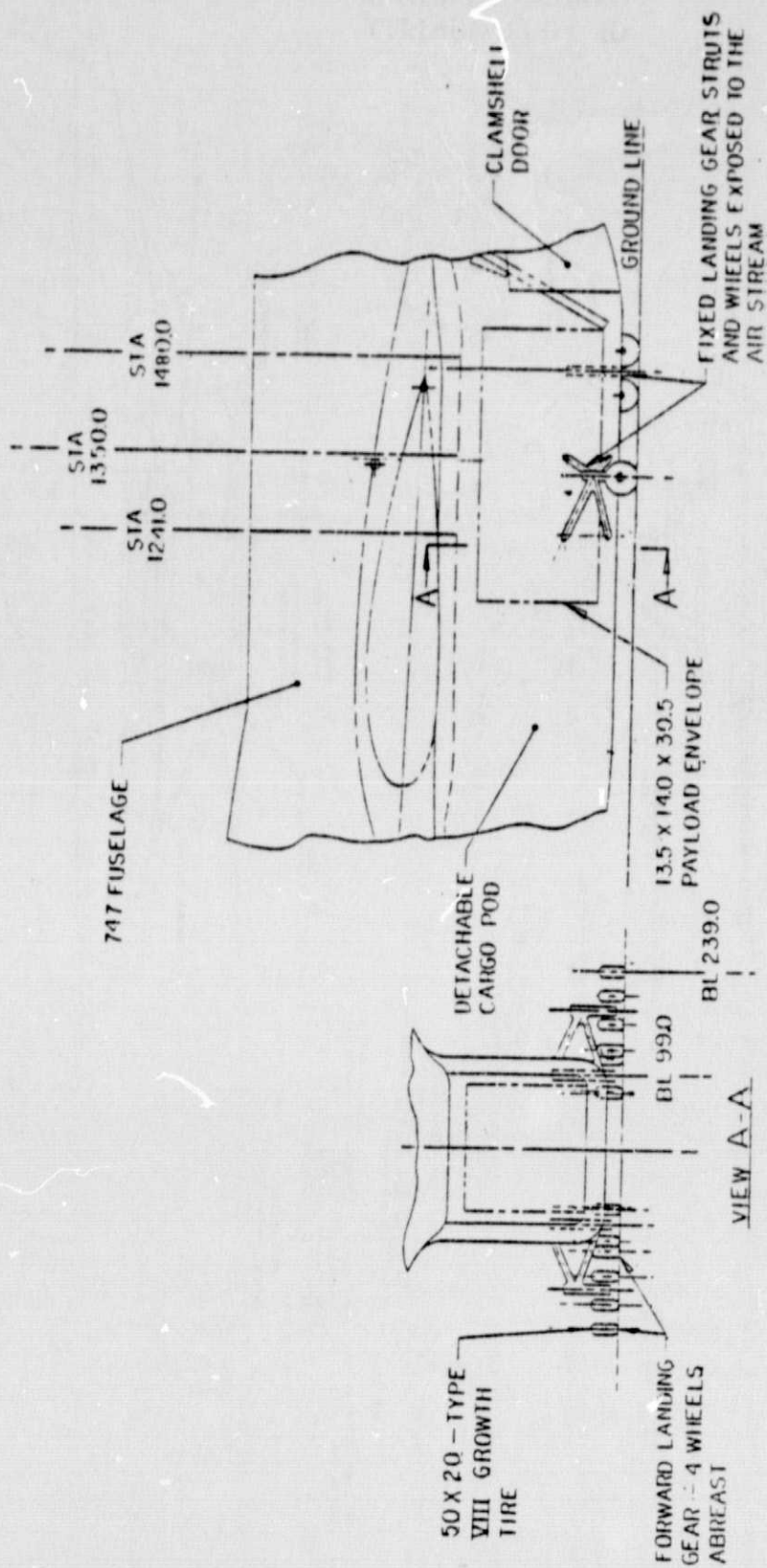


Figure 3. - Boeing 747 with external cargo pod - fixed, fully exposed, landing gear

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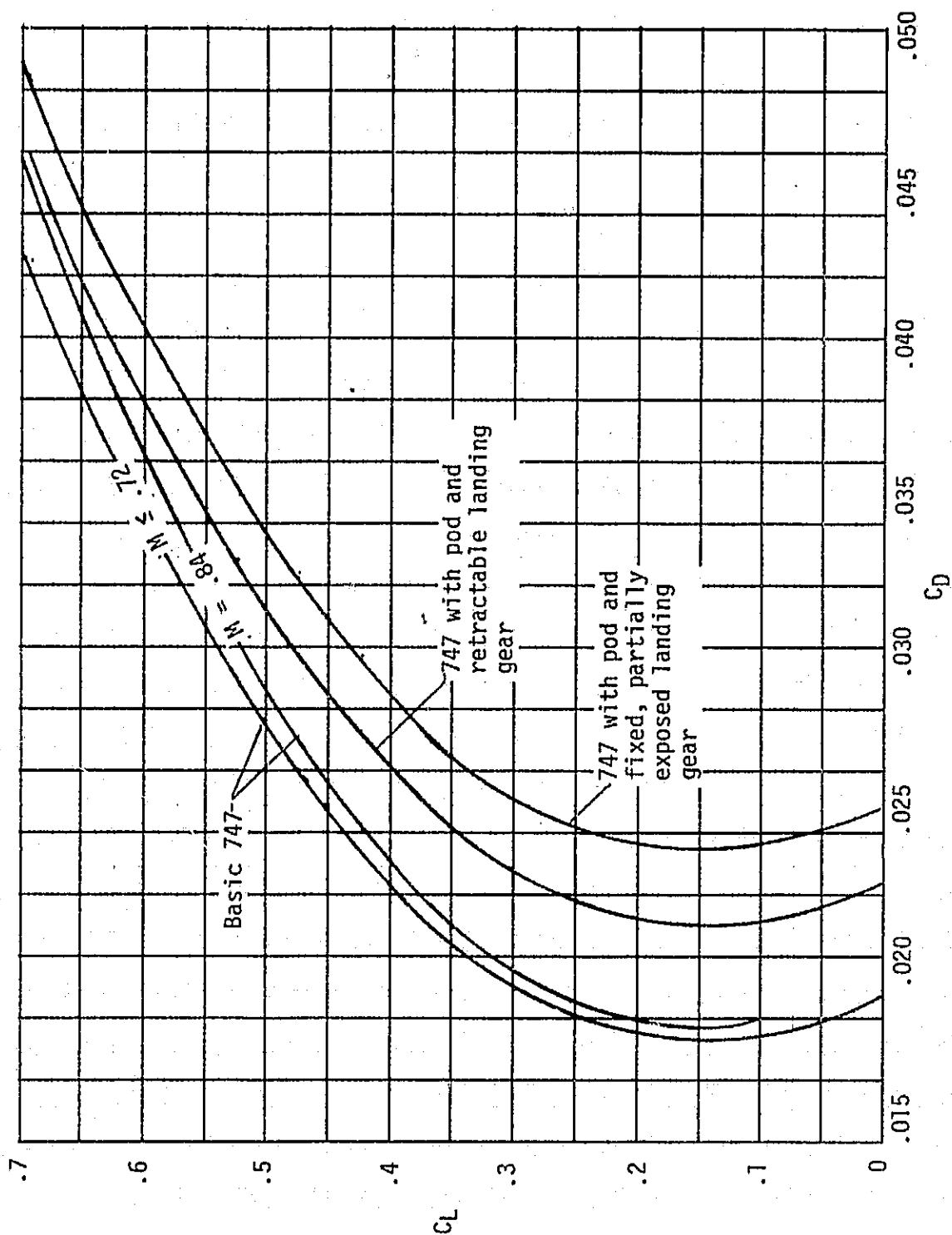


Figure 4. - Cruise drag polars

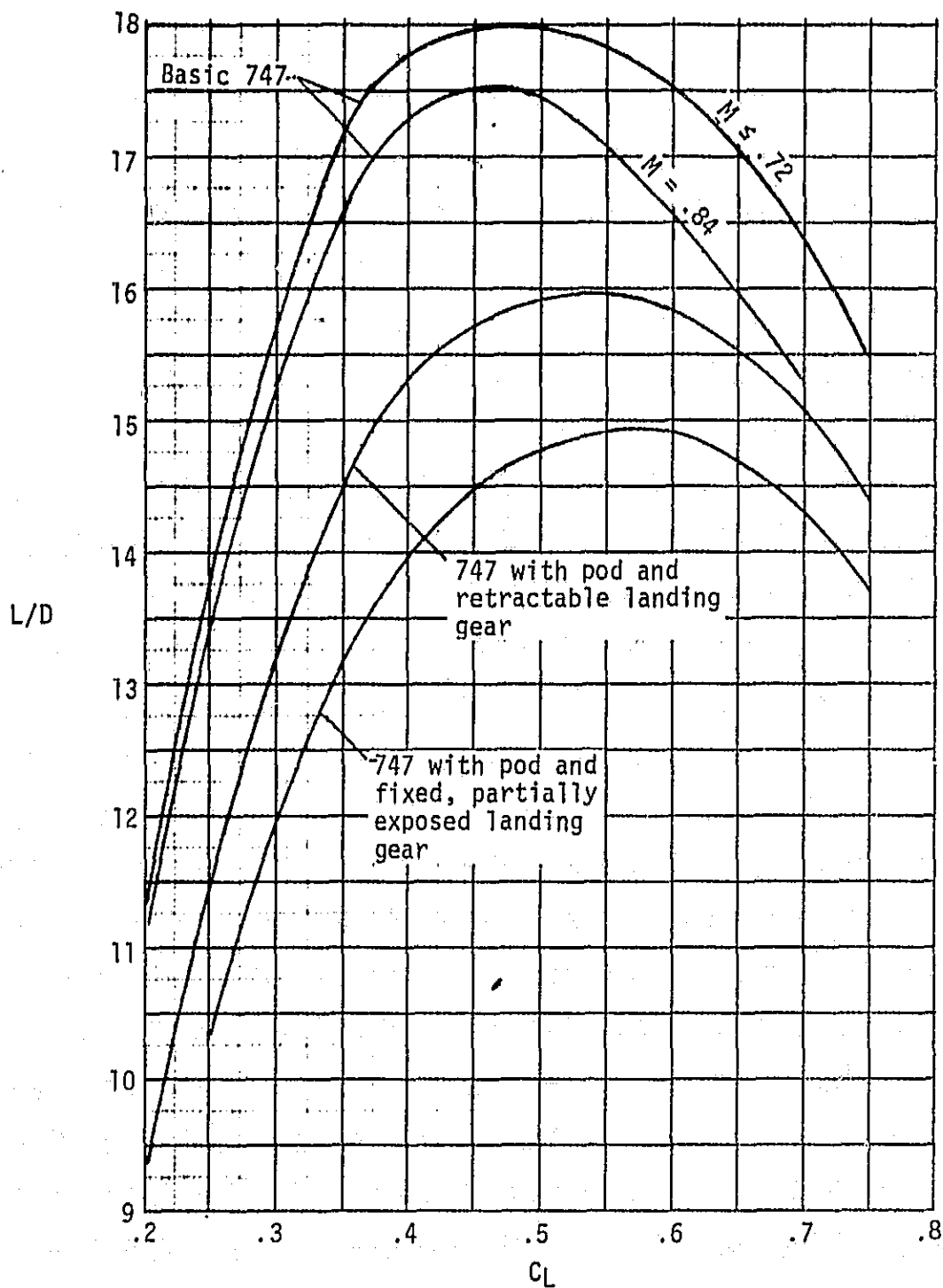


Figure 5. - Cruise lift to drag ratios

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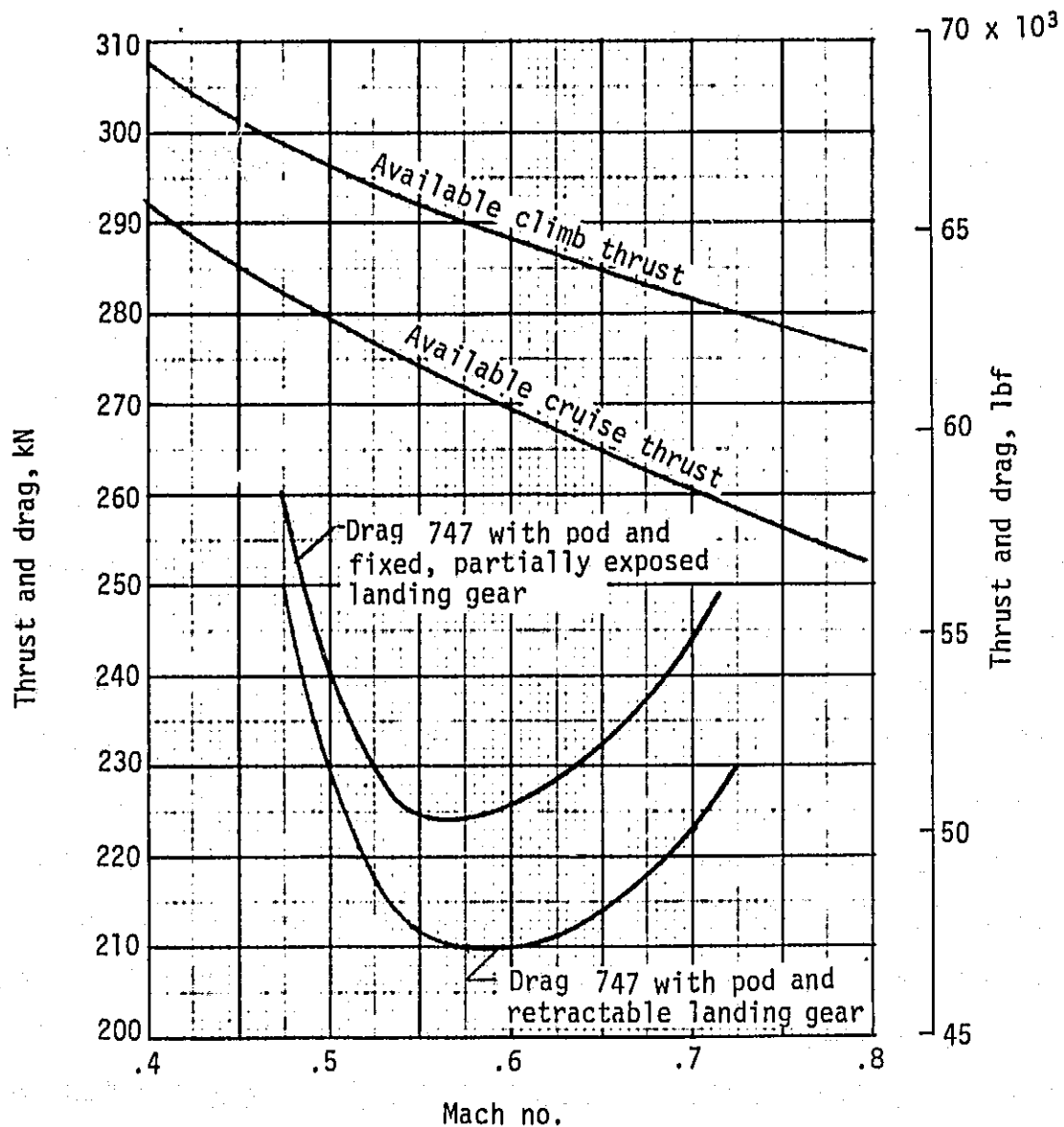


Figure 6. - Cruise drag and available thrust ;  
Gross weight = 3 336 166 N (750 000 lbf) ;  
Altitude = 5.486 km (18 000 ft) ; P&W JT9D-7 engines.

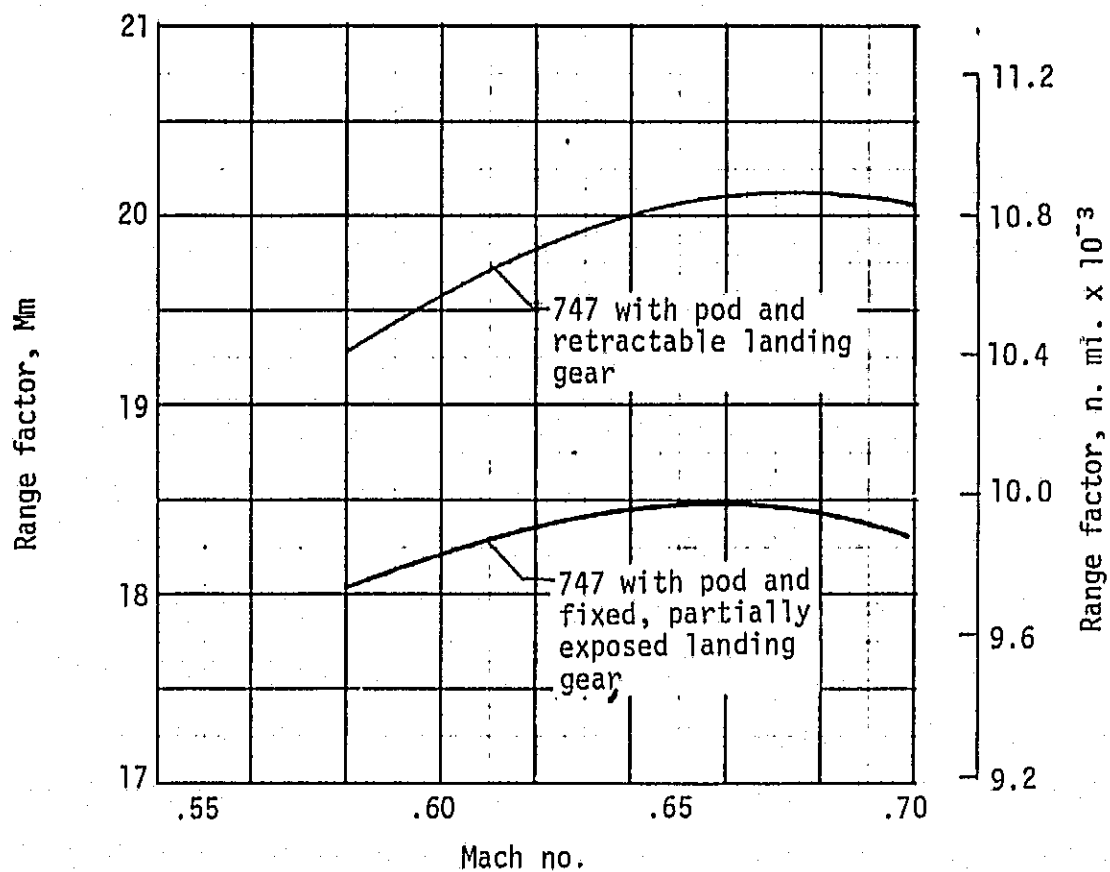


Figure 7. - Range factor  $\frac{\sqrt{\theta}}{TSFC} M \frac{L}{D} a_0$  at 5.486 km (18 000 ft) altitude



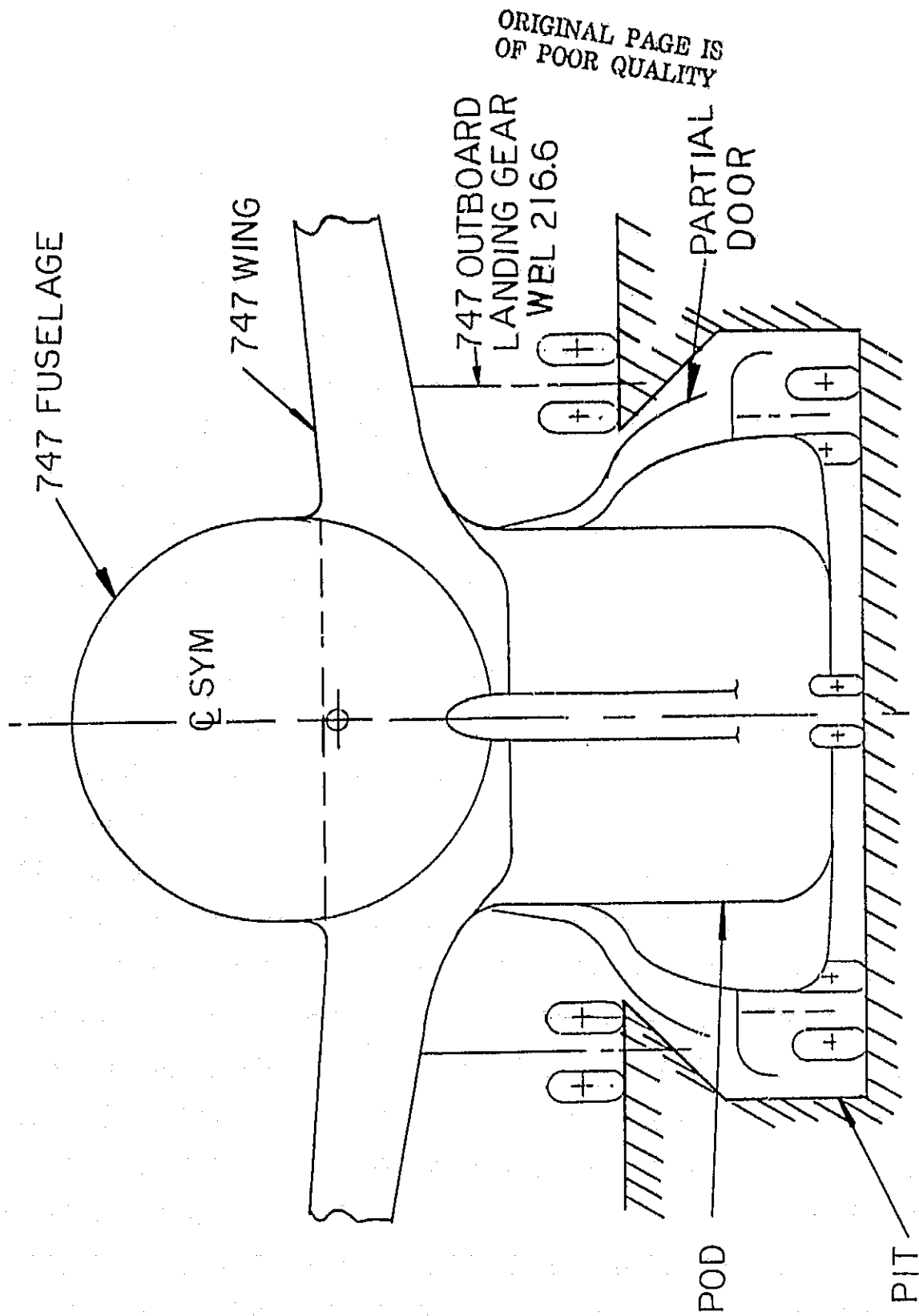


Figure 8. - Boeing 747/pod loading pit schematic